The External Calibrator for Hydrogen Arrays

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ABSTRACT

We describe the External Calibrator for Hydrogen Observatories (ECHO)

1. Introduction

A new generation of radio arrays is being developed that use large numbers of low-cost elements, such as phased tiles of dipole antennas. This is made possible by developments in digital technology and enables exploration of new windows on the universe such as the epoch of reionization (EoR) via the redshifted 21 cm line (Morales & Wyithe 2010; Madau et al. 1997; Loeb & Zaldarriaga 2004; Loeb & Barkana 2001; Furlanetto et al. 2006). Precise calibration of the primary beams of these dipole arrays has been found to be crucial to analysis of observations from the the Murchison Widefield Array (MWA; Tingay et al. (2013); Bowman et al. (2013)), the Precision Array for Probing the Epoch of Reionization (PAPER; Pober et al. (2013); Parsons et al. (2010); Jacobs et al. (2011)), and the Low Frequency Array (LOFAR; Yatawatta et al. (2013)). Beam calibration of low frequency dipole arrays poses several complications compared to traditional dish antennas. Most notable is that holographic beam calibration is not possible because the dipole array beams are steered electronically and are unique at every pointing direction. Drift scan calibration of dipole array beams is possible, but requires the test antenna/array to be embedded within an existing array that generates sufficient sensitivity to isolate a large number of radio sources to provide many tracks through the beam. Pober et al. (2012) have employed symmetry arguments to reduce the needed number of sources on the sky and improve the result for PAPER antennas, but this is not possible in general for more complicated dipole array beam patterns. Attempts have been made to use anechoic chambers to calibrate low-frequency phased arrays, but the measurements suffer since even the largest chambers cannot extend into the farfield pattern and the RF absorber material used in the chambers performs poorly below 150 MHz, creating reflections and resonances. Mapping of the dipole beams using the Orbcomm constellation of satellites has proven effective (Neben, Bradley and Hewitt in prep) but is limited to only a single frequency (138 MHz).

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2. Design and Method

3. Calibration

The first full scale test of the ECHO system was done in August, 2015 at the National Radio Astronomy Observatory (NRAO) site in Green Bank, WV. Two dual-polarization dipoles (see Fig. 3) used in the development of a calibration technique utilizing the ORBCOMM satellite constellation (Neben et al. 2015) were used as the AUTs. With a dipole length of 90.4 cm and a Valon synth frequency of 137.554 MHz[2], a flight radius of 100m was chosen, well into the far-field of the dipoles. Choosing a flight speed of 0.2 dam s^{-1} and $N_{side} = 8$, each flight ECHO performed took 60 min. Four total flights were performed as each antenna contained two dipoles and thus needed to be tested with two flights, one with a polarization of the BicoLOG matching the polarization of one of the dipoles. This also allowed cross-polarization measurements of each antenna to be made.

3.1. Maps

The resulting maps can be seen somewhere... eventually...

[2]Is this the right frequency

3.2. Comparison to Orbcomm Ratio Maps

4. MWA Tile

4.1. Data

4.2. Systematic Variation

4.3. Comparison to Orbcomm Maps

5. Conclusion

6. Acknowledgments

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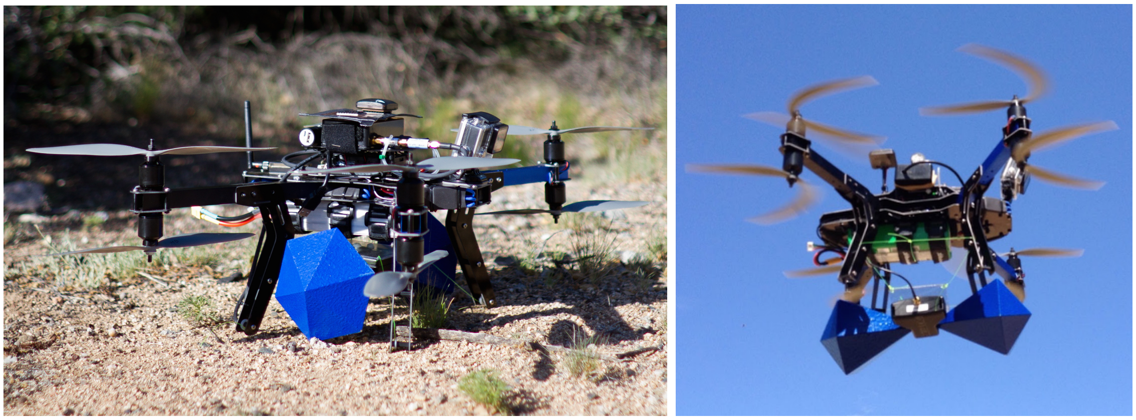

Fig. 1.— 3DR X8 octoquad drone prior to launch (left) and in flight (right). The Valon synth is contained in the black project box mounted on top of the drone. A copper plate, which acts as shielding from the electronics below, with the attached GPS magnetometer can be seen atop the project box. Beneath the drone, the BicoLOG antenna, which is blue in color, can be seen.

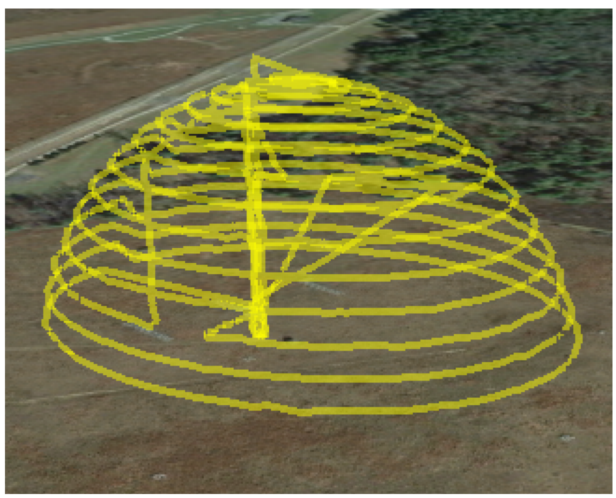

Fig. 2.— Actual flight path of drone in Green Bank, WV. The spiral pattern from horizon to zenith is generated from a Healpix map with parameter $N_{side} = 8$.

Fig. 3.— Dual-polarization dipole antenna seated on a 2 m $\times$ 2 m ground screen. Located at the NRAO Green Bank, WV site and used for ECHO testing in August, 2015.